UNITED STATES PATENT APPLICATION

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FOR

CATALYZER

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CATALYZER

FIELD OF THE INVENTION

[0001] The present invention relates to the field of catalyzer technology. More particular, the present invention relates to a catalyzer with plane sheets, each two successive plane sheets forming a channel, and a catalytic coating deposited on predetermined sections of the channels opposite uncoated sections.

BACKGROUND OF THE INVENTION

[0002] A number of publications describe catalytic carrier structures in which the overheating of the catalytic coatings is reduced by limiting the maximum heterogeneous fuel conversion to approximately 50%. This is achieved by providing the channels arranged inside the catalyzer alternately with a catalytic coating, i.e. coated and non-coated channels are alternated (cf. US-A-4,870,824 or US-A-5,346,389 or US-A-5,328,359). In the solutions described in US-A-5,346,389 or US-A-5,328,359, either an alternately coated, corrugated carrier sheet is folded in zigzag shape, or a structure of two superposed sheets is rolled up. US-A-5,518,697 or US-A-5,512,250 furthermore disclose a three-layer structure in which the coated and uncoated channels have different dimensions in order to further improve the cooling of the catalytic coatings.

[0003] In order to prevent a deactivation of the catalytic coatings, it is critical that their surface temperature is maintained below a predetermined value that depends on the type of the catalyzer material. For example, in the case of PdO, a reduction to Partial diffuser sets in at temperatures above approximately 900°C (at pressures > 15 bar). In the above-mentioned publications, the surface temperature is limited in that not all surfaces are provided with a catalytic coating. In US-A-5,328,359, the surface temperature remains high under the operating conditions of a gas turbine: $T_{surface} = T_{in} + 1/2T_{ad}$ typically reaches 1,000°C, whereby $T_{surface}$ is the surface temperature, T_{in} is the temperature at the inlet of the catalyzer, and T_{ad} is the adiabatic combustion temperature. In US-A-5,518,697, additional convective cooling is achieved by enlarging the cross-section surfaces of

the non-coated channels in relation to the coated channels. In both cases, however, channels exist that are not provided with any sort of catalytic coating. Under the conditions present with a gas turbine (mixtures with $\lambda=2.2$ at pressures > 15 bar), there exists, however, the concrete risk of homogeneous ignition near the surfaces, particularly in the uncoated channels, since no reduction of the fuel concentration occurs there. This problem is increased in that the uncoated channels at the same time are those channels with the greatest hydraulic diameter.

SUMMARY OF THE INVENTION

[0004] It is therefore the objective of the invention to create a catalyzer or catalytically coated carrier structure that simultaneously enables improved cooling of the catalytic surface and safely avoids the homogeneous ignition in the catalyzer.

[0005] The objective can be solved by a catalyzer with a plurality of plane sheets arranged superposed and spaced apart from each other in a stack. Each two successive plane sheets define a straight channel that extends parallel to a flow direction and is delimited by the plane sheets. A catalytic coating on a predetermined section of each channel defines a coated section and is positioned opposite to an uncoated section of the channel. At least a portion of a heat radiation emitted from the catalytic coating is absorbed by the uncoated section. The plane sheets are coated in such a way that catalytic coatings are present in all channels; that the catalytic coatings are limited to predetermined sections of the channels; and that inside the channels, uncoated sections in each case are positioned opposite to sections with the catalytic coatings in order to absorb the heat radiation emitted by the catalytic coatings during operation. The channels are formed by corrugated sheets, each of which is arranged between the plane sheets and is connected to them.

[0006] The solution utilizes the fact that the hot surfaces of the catalytic coatings emit a certain part of heat in the form of radiation. This radiation energy can be absorbed by adjoining catalytically non-active surfaces and removed by convective

cooling. At the temperatures of interest for the gas turbine operation, the heat emitted by radiation, for example, may amount to approximately 30% of the convectively emitted heat. This means that if the catalytically inactive, heat-absorbing surfaces are optimized, the cooling can be clearly improved. Through the alternation of coated and uncoated areas, the conditions in all channels, while utilizing the heat emission by radiation, are simultaneously homogenized, eliminating the risk of a homogeneous ignition. In order to increase the throughput, the coating surface is enlarged in that sections of the corrugated sheets are also catalytically coated in the same manner as the plane sheets.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Preferred embodiments of the invention are disclosed in the following description and illustrated in the accompanying drawings, in which:

[0008] Fig. 1 shows a schematic view in the flow direction onto the inlet side of a catalyzer according to a first preferred exemplary embodiment of the invention.

[0009] Fig. 2 shows the view from the top onto different coated and uncoated sheets of the catalyzer according to Fig. 1.

[0010] Fig. 3 shows the longitudinal section through the catalyzer from Fig. 1 along plane III-III.

[0011] Fig. 4 shows an alternative type of coating (with respect to Fig. 2) of the sheets of a catalyzer according to the invention.

[0012] Fig. 5 shows a view comparable to Fig. 1 of a catalyzer according to a second preferred exemplary embodiment of the invention with a coating according to Fig. 4.

[0013] Fig. 6 shows the longitudinal section through the catalyzer from Fig. 5 along plane VI-VI.

[0014] Fig. 7 shows another possibility of the coating within the framework of the invention.

[0015] Fig. 8 shows a view comparable to Fig. 2 with various coated and uncoated sheets of the catalyst according to another preferred exemplary embodiment of the invention.

[0016] Fig. 9 shows the longitudinal section through a catalyst with a coating according to Fig. 8.

[0017] Fig. 10 shows the frontal view, comparable to Fig. 1 and 5, of a catalyzer with a coating according to Fig. 7.

[0018] Fig. 11 shows another embodiment of the invention, in which sections of the corrugated sheets between the plane sheets are coated.

[0019] Fig. 12 shows a longitudinal section through the catalyzer analog to Fig. 6, for a further embodiment in which sections of all plane sheets have been coated.

DETAILED DESCRIPTION OF THE INVENTION

[0020] The present invention is directed to a catalyzer. The term catalyzer in the present case means a carrier structure provided with a catalytic coating. The carrier structure according to the invention can be used for many exothermic catalytic reactions, for example for catalytic combustion and synthetic gas generation, especially in cases where a concomitant gas phase reaction must be prevented.

[0021] Fig. 1 shows a schematic view in the flow direction onto the inlet side of the catalyzer according to a first preferred exemplary embodiment of the invention. The catalyzer 10, shown partially, comprises a stack of plane sheets S1,...,S4 and corrugated sheets CS1,...,CS4, arranged alternately in the stack and connected with each other. The stack of sheets S1,...,S4 and CS1,...,CS4 forms the structure of the catalyzer 10. The corrugated sheets CS1,...,CS4 create a plurality of separate, parallel channels between adjoining, plane sheets, of which four selected and superposed sheets in Fig. 1 are designated with the reference numbers C1,...,C4.

[0022] The corrugated sheets CS1,...,CS4 are very thin and typically have a thickness of 0.05 mm. The plane sheets S1,...,S4 are, for reasons of good solid-

state heat conduction, significantly thicker than the former. The plane sheets S1, S3 and S2, S4 are, taken by themselves, practically identical (as seen in Fig. 2), but are integrated into the stack in a different arrangement. The entire catalyzer 10 is constructed of a specific number of superposed units, whereby each unit comprises a sequence of sheets S1, CS2, S2, CS3, and thus has a height of two channel diameters.

[0023] The catalytic coating 11, 12 necessary for the catalyzer function is arranged in the form of bands extending in flow direction FD (Fig. 2) on the plane sheets S1,...,S4 in a certain configuration: the sheets, which have a total length L_{total}, are divided in the flow direction FD into two or more different sections 13, 14 that are provided alternately with catalytic coatings 11, 12 or do not have any catalytic coatings at all. Within a section (section 13 in the plane sheet S1 or section 14 in the plane sheet S2 in Fig. 2) provided with catalytic coatings, the sheet is coated transversely to the flow direction FD across the width w, coated alternately in each case on the top (catalytic coating 11) and on the bottom (catalytic coating 12), so that the plane sheets S1,...,S4 are not provided at any point with a catalytic coating on both sides at the same time. In adjoining plane sheets (e.g., S1 and S2), the sections provided with catalytic coatings 11, 12 are offset to each other in such a way (Fig. 2, 3) that the coatings are alternated. At first, the sheet S1 is coated in section 13 across the length L_{coated}, while the sheet S2 is uncoated in this section. In the next section 14, the sheet S1 is then uncoated, while the sheet S2 is coated. Each section therefore has specific channels (marked in Fig. 1 and Fig. 5 with an "*") which do not have any catalytic coating 11, 12 in this section.

[0024] Figs. 1 and 3 show how the sheets CS2, S2, and CS3 are arranged on the first length L_{coated} (the first section 13) so that they form channels with a relatively large surface, whose uncoated walls absorb the heat radiated from the catalytically active coatings 11, 12 on sheets S1 and S3 and remove it by convection in the respective channel. Fig. 3 clearly distinguishes between the coated and uncoated channels in one section (13). In the following section (14), the sheets CS1, S1,

CS2, and CS3, S3, CS4 form the uncoated channels, while the sheet S2 is catalytically active and radiates heat. It is advantageous if the catalyzer 10 has more than two sections 13, 14 with alternating coating, since this improves the uniformity of the temperature and fuel concentration within the catalyst 10. In the interest of this uniformity and also a good mixing of the discharged gases, there should always be an even number of sections 13, 14 or $L_{total} = 2nL_{coated}$ with $n=1,2,3,\ldots$ should apply.

[0025] The various types of heat transport occurring with the exemplary embodiment can be explained with Fig. 3: Of the uncoated surfaces of sheets S1,...,S4, heat that has been emitted by a catalytic coating and absorbed is transferred by a convective heat transport 17 (thin, straight arrows in Fig. 3) to the flow in the channel. Of the sections of sheets S1,...,S4 provided with a catalytic coating, heat is transferred via a combined convective and radiating heat transport 18 (thick, straight arrows in Fig. 3) into the atmosphere. And finally, another heat transport 19 takes place via solid-state conduction inside sheets S1,...,S4 (thin, curved arrows in Fig. 3).

[0026] Fig. 3 shows clearly that the plane sheets S1,...,S4 each are uncoated at the inlet and at the outlet of the catalyzer. It is preferred that this uncoated surface has a depth of approximately 2-5 mm at the inlet and a depth of approximately 10-15 mm at the outlet. On the one hand, this achieves a better mechanical strength in these areas, and on the other hand, allows for a better manufacturing of the catalyzer because the plane sheets S1,...,S4 can be welded better to the corrugated sheets CS1,...,CS4. At the outlet, the uncoated area also functions as radiation protection against a homogeneous flame or a hot flame outside of the catalyzer.

[0027] The basic advantages of the configurations shown in Fig. 1-3 are the two following:

- The surface absorbing the heat radiation is maximized so that the surface of the catalytic coatings 11, 12 is cooled to an acceptable level.
- All channels are provided in at least one of the sections with a catalytic coating, so that a uniform reduction of the fuel content towards the outlet

of the catalyzer is ensured, preventing a homogeneous ignition within the catalyzer.

[**0028**] However, there are additional advantages through the shown catalyzer structure: Firstly, the hot gases exiting from the catalyzer are significantly more homogeneous (i.e. with the same degree of conversion in all channels) than with conventional catalyzer configurations. Since such a catalytic reactor is used in gas turbines where one part of the fuel is burned homogeneously, this enables a combustion that is easier to control and is cleaner, i.e. with lower NOx and CO concentrations, downstream from the catalyzer. On the other hand, the sheets S1,...,S4 provided with the catalytic coating 11, 12 are relatively thick - as already mentioned above - so that the heat can be passed further upstream in order to improve (a) the cooling in the area of the coating and (b) the "light-off" in the upstream areas.

[**0029**] Another point is related to pressure losses: In previous technical solutions, contorted channels that result in higher pressure losses and are more susceptible to structural deformations during operation (i.e. the channels bend and in this way noticeably change the effect of the catalyzer) were proposed. In contrast, if - as in the present solution - straight channels are used, not only are the pressure losses that play a critical role in the efficiency of gas turbines reduced, but the production and assembly processes are also significantly simplified. Finally, the surfaces of the channels not provided with catalytic coatings can be provided with a special coating that improves the absorption of the radiated heat. This coating also could promote, for example, recombination reactions of radicals (OH, H, O) in the gas phase in order to inhibit a homogeneous ignition.

[**0030**] In a modification of the exemplary embodiment shown in Fig. 1 to 3, the cooling of the coated surfaces can be improved with an expansion of the conductive heat transport (19 in Fig. 3). According to Fig. 4, this is achieved by providing islet-like catalytic coatings 15, 16, instead of the continuous bands with catalytic coating (Fig. 2). Essentially, heat is transported here by way of a conductive heat transport 19 from the hot islets of the catalytic coating 15, 16 into

the relatively cool regions between the islets and removed from there by a convective heat transport to the flowing medium. A frontal view of the structure of the resulting catalyzer 20 comparable to Fig. 1 is shown in Fig. 5. Fig. 6 shows the longitudinal section through the catalyzer 20 along plane VI-VI in Fig. 5. This also realizes a combination of a purely convective heat transport 17, a mixed convective and radiating heat transport 18, and a conductive heat transport 19.

[0032] In comparison to the channel diameter, the islets with the catalytic coating 15, 16 can be made relatively small, resulting in the following advantages:

- An even higher uniformity in all channels.
- An even better removal of the heat from the catalytically coated islets, since the lengths for the heat conduction are reduced (the heat conduction is reversely proportional to the diameter of the islets).

[0033] The small dimensions of the catalytically coated islets 15, 16 make it possible to accommodate more than one row (in flow direction). An example of such a configuration is shown in Fig. 10 in a view comparable to Fig. 5. But it would also be possible to arrange the catalytically coated islets 15, 16 uniformly alternating on sheets S1,...,S4 in the manner shown in Fig. 7.

[0034] In order to increase the throughput, it is advantageous that sections of the corrugated sheets CS1,...,CS4 also are coated in the same manner as the plane sheets S1,...,S4, whereby here also, for reasons of heat removal, both sides of the corrugated sheets are not provided with a coated surface at the same time. Compared to the exemplary embodiments shown in Fig. 1 to 7, in which the corrugated sheets CS1,...,CS4 are uncoated, this has a somewhat negative effect on the temperature. The coating of sections of the corrugated and plane sheets again should take place in such a way that inside the channels C1 ,...,C4 sections with the catalytic coatings 11, 12, 15, 16 each again have uncoated sections positioned opposite from them.

[0035] Fig. 11 shows a schematic portrayal of the view in the flow direction onto the inlet side of a catalyzer in such a further exemplary embodiment. In

comparison to the first exemplary embodiment shown in Fig. 1, in which uncoated, corrugated sheets CS1,...,CS4 were used, Fig. 11 clearly shows that the catalytic coating surface within the channels C1,...,C4 is distinctly enlarged by using corrugated sheets with coated sections (degree of coating of significantly more than 25%), and the catalyzer throughput therefore can be increased advantageously. Further, in this example, both the plane sheets S1,...,S4 as well as the corrugated sheets CS1,...,CS4 are not provided at any point of the sheets with a catalytically coating both on their top and bottom side at the same time, so that the heat removal is ensured during operation. Fig. 11 also shows that in contrast to the exemplary embodiment shown in Fig. 1, plane and corrugated sheets S1,..,S4, CS1,...,CS4 with an approximately identical thickness can be used.

[0036] A further modification of the exemplary embodiment shown in Fig. 1 to 3, and in Fig. 11, in which all types of catalytic coatings explained so far are used, is shown in Fig. 8 and 9. The catalyzer 30 shown there uses plane sheets S1,...,S4, the length of which is no longer L_{total} but rather only L_{coated}. The sheets are provided on this reduced length completely, according to one of the types described previously, with catalytic coatings 11, 12 (or 15, 16). The view from the front onto the catalyzer 30 is similar to the one in Fig. 1. The longitudinal section in Fig. 9, however, shows the differences of the configuration with the short channel sections that transition into each other. The advantages of such a modification are double:

- It enables a mixing between the channels, which further improves the uniformity of temperature and fuel concentration.
- The formation of (laminar) marginal layers along the catalytically coated surfaces is interrupted repeatedly, so that the reaction process is removed from an area with diffusion-controlled reaction, and in this way the surface temperatures are reduced. The length L_{coated} hereby must be in the same magnitude as the lengths over which the marginal layers develop.

[0037] Another configuration is characterized in that all plane sheets S1,...,S4 are continuously coated in the same manner as shown in Fig. 7. Instead of the alternating coating on adjoining sheets, the structure shown in Fig. 10 is obtained. Since in this case the uncoated areas of the channels are significantly reduced in comparison to the variations described further above, cooling by heat radiation is reduced, and the main emphasis is on cooling by heat conduction and convective heat transport.

[0038] Fig. 12 shows another embodiment analogously to Fig. 6. In comparison to the embodiment according to Fig. 6, a larger coating surface exists here since every plane sheet S1,...,S4 is coated, not just every second one.

[0039] Overall, the invention results in a catalyzer that is characterized by the following properties and advantages:

- The surface temperature of the catalytically coated areas is maintained under the temperature that would result in deactivation.
- The risk of homogeneous ignition in the catalyzer is minimized.
- Heat is conducted into the (thicker) carrier plates for the coating; this improves the "light-off," and, because of thermal inertia, the stability of the system is also improved.
- Pressure losses are reduced, and the production is improved or simplified.
- The hot gases exiting the catalyzer are mixed more uniformly, resulting in a more controllable, homogeneous combustion and a cleaner combustion with lower NOx and CO concentrations.

[0040] Naturally, the invention is not limited to the exemplary embodiments described. It would be possible, for example, in order to form channels C1,...,C4, to use coated, corrugated sheets CS1,..,CS4 in all described exemplary embodiments instead of the uncoated, corrugated sheets CS1,...,CS4.